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C-130 ENGINE COMPRESSOR WASH STUDY, HQ ACC/CEV

ARMSTRONG LABORATORY

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This effort was conducted to characterize the waste stream from engine compressor washing operations on C-130 aircraft. Surveys at three bases were used to identify the levels of metals and other contaminants in the waste water. The report provides data which can assist bases in determining the best management plan for dealing with the compressor waste stream. HQ ACC/CEV funded this study.

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C-130 ENGINE COMPRESSOR WASH STUDY

INTRODUCTION

The USAF Armstrong Laboratory, Occupational and Environmental Health Directorate, Bioenvironmental Engineering Division, Water Quality Branch (AL/OEBW) evaluated five C-130 compressor washing operations at three major Air Force installations. The surveys were conducted at: Little Rock Air Force Base (AFB), Arkansas, 22 - 27 Jan 95; Patrick AFB, Florida, 20 -24 Feb 95; and Davis-Monthan AFB, Arizona, 6 -10 Mar 95. The purpose of the evaluation was threefold: (1) Characterize the gas path waste products generated from the compressor washing operation; (2) Determine levels of cadmium produced from this operation; (3) Provide suitable information for treatability.

The Environmental Sciences Branch (AL/OEMH) conducted a health assessment of C-130 Compressor Washing Operations at Little Rock AFB from 15-20 Jul 94. The purpose of the OEMH evaluation was to determine the health impacts from the washing operations. The data produced during the 1994 survey provided additional values useful to the OEBW 1995 evaluation.

SAMPLING METHODOLOGY

Two sampling methods were employed during this evaluation: Single Engine Catch, and Single Aircraft Composite sampling methods. Both methods consisted of collecting gas path waste from the compressor washing operation in manmade catch basins. The catch basins were constructed with four 10-16 ft long wood planks nailed together in a square shape and covered with plastic visqueen. The catch basins were positioned to optimize the capture of waste discharged from the engine exhaust. Approximately 30 - 40 gallons of waste product were captured in the catch basins for the entire operation. Subsequently, water was collected from the basins by means of a five quart stainless steel pitcher and poured into a compositing jar or sample containers. When pouring water into sample containers, the compositing jar or pitcher was continuously stirred to insure homogeneity. For dissolved metals samples, OEBW personnel vacuum filtered the water through 0.7um filters before pouring into sample containers. The dissolved metals results in this study are equivalent to Toxicity Characteristic Leaching Procedure (TCLP) analyses, and may be used to characterize the waste if managed under hazardous waste rules.

The single engine catch method was used solely at Little Rock AFB. This method segregated the rinse and wash segments of each of the four engines during the operation. The major purpose for performing this method was to determine each engine contribution to the total waste. Great care was taken during the sampling event to reduce the possibility of cross-contamination. Prior to the start of each engine's rinse and washing segments, the catch basins were re-positioned. In addition, the visqueen in each catch basin was changed between the rinse and wash segment of the operation.

The single aircraft composite method was used at Patrick AFB and Davis-Monthan AFB. This sampling method characterized the wastewater as a whole from the entire operation. Both rinse and wash segments were collected from all four engines and composited. Equal aliquots were taken from each catch basin and mixed into a five gallon glass container. From this container individual samples were poured and analyzed. Table 1 below indicates the analyses done at each of the six cleaning operations, including the "Sea Air" washing operation at Patrick AFB:

TABLE 1. ANALYSES PERFORMED

ANALYTE	EPA METHOD	ANALYTE	EPA METHOD
ALUMINUM	200.7	TOTAL DISSOLVED SOLIDS	160.3
ARSENIC	206.2	TOTAL SUSPENDED SOLIDS	160.1
BARIUM	200.7	SURFACTANTS	425.1
BERYLLIUM	210.7	ALKALINITY	310.2
CADMIUM	200.7	CHEMICAL OXYGEN DEMAND	410.4
CHROMIUM	200.7	AMMONIA	350.1
COPPER	200.7	CHLORIDE	325.2
IRON	200.7	NITRATES	353.1
LEAD	200.7	NITRITES	353.1
MAGNESIUM	200.7	PHOSPHORUS	365.1
MANGANESE	200.7	SULFATE	300.1
MERCURY	245.2	TOTAL PETROLEUM HYDROCARBONS	418.1
NICKEL	200.7	TOTAL ORGANIC CARBONS	415.1
SILVER	200.7	OIL AND GREASE	413.1
ZINC	200.7		

A field Quality Assurance/Quality Control (QA/QC) program was used during this evaluation to verify the accuracy and reproducibility of laboratory results. The following is an enumeration of samples sent to the analytical laboratory to validate the integrity of the samples collected:

Equipment Blank Sample: Equipment blank samples were collected by pouring laboratory grade water through the sampling collection media (pitcher, collection basin, etc.) into the appropriate sample container. Preservation and shipping was conducted in the same manner as the normally collected samples. This sampling series serves as a check on contamination from sampling media.

Spike Samples: Spike samples were collected by filling the appropriate sample containers with a laboratory prepared, known concentration, spike standard solution. The spike standard solutions were prepared by Armstrong Laboratory Analytical Service Division (AL/OEA) Quality Assurance, Quality Control Branch. This series of samples in conjunction with AL/OEA Quality Assurance Plan serves as check on the sample collection preservation, and reproducibility of analytical results.

Duplicate Samples: Duplicate samples are aliquots samples taken form the same source, and analyzed independently. These samples serve as a measure of precision, which is the agreement between a set of replicate measurements without assumption or knowledge of the true value.

Reagent Blank Samples: Reagent blank samples were collected by filling the appropriate analysis sample container with laboratory grade water and placing the preservative into the container. This series serves as a check on the purity of the reagents used and elimination of any preservative contributing to false analytical results.

RESULTS AND DISCUSSION

Gas Path Waste Characterization at Little Rock AFB, AR

The gas path waste samples were collected from a C-130 bearing the tail number 793. The aircraft accumulated 249 flying hours prior to the compressor wash evaluation. Samples were taken

from the aircraft using the single engine catch method. During this survey, particular emphasis was made on the wastewater recovery system (baffle box) sampling feasibility. This system was constructed by personnel at Little Rock AFB to capture 100% of the waste discharged from this operation. Engine number 4 was used to test this system.

The total operation used approximately 55 gallons of water and 28 gallons of soap. For QA/QC purposes, separate soap and water samples were taken. The sampling results are located in Table 1.

Gas Path Waste Characterization at Patrick AFB, FL

Sampling at Patrick AFB focused on two separate issues: 1) Characterize the gas path waste generated from the C-130 compressor washing operation; and 2) Determine the concentration, if any, of cadmium produced from the C-130 "Sea Air" wash. Three C-130 aircraft were used during the survey at Patrick AFB. Two of the three C-130's surveyed belonged to the 301 AFRES RQS . The other C-130 was maintained by the 71 RQS, an active duty squadron at Patrick. The tail numbers of the aircraft surveyed were 5830, 5833, and 801, respectively.

The gas path sampling of the C-130 at Patrick was accomplish by the single aircraft composite method. The 301 RQS performs compressor washes on their aircraft every 15 days on the average. The physical appearance of the samples were less turbid than those taken at Little Rock AFB. The C-130 aircraft we sampled from the 71 RQS had not had a compressor wash for six months previously. The samples were extremely turbid. The concentrations of cadmium in the 71st gas path samples were significantly higher than the 301st.

Sample collection for the sea air wash was taken in the same manner as the compressor washing. The sea air washing was accomplished by using a 500 gallon capacity fire truck and applying a large volume of water over the aircraft. Initially, high pressure water was applied to the front surface of the aircraft. Then water was applied to the wing, tail and fuselage area. We positioned the catch basin in a manner to capture the fluid draining from the area where exhaust from the engines contacts the aircraft body. The specific areas included; the bottom portion of the wings nearest the exhaust, the back portion of the aircraft, and portions of the fuselage. Again, samples were composited from both sides of the aircraft. This procedure is only a fuselage wash, and not a compressor wash.

Gas Path Waste Characterization at Davis-Monthan AFB, AZ

Samples of C-130 compressor wash wastewater were collected at Davis-Monthan AFB to provide additional data to support treatability and waste issues. OEB personnel sampled two C-130 aircraft at D-MAFB, tail numbers 1588 and 1832.

For Aircraft Number 1588, samples were collected from the compressor washing operation with a manmade catch basin. Composite samples, representing each of the four engines were taken. Both wash and rinse phase were collected together as a composite. The date of the last compressor wash on this aircraft is unknown, possibly occurring over five years ago.

For Aircraft Number 1832, samples were collected in the same fashion as the other C-130 (Single Aircraft Composite Method). It was learned after the washing of the first engine the soap put in the soap tank was a general purpose cleaner and not a gas path cleaner. After the first engine had been thoroughly washed, the last three engines were washed and rinsed with water only. The samples collected for this aircraft were composite samples, representing each of the three remaining engines. Wash and rinse phases were composited.

Survey Results

Table 2 lists the analytical results for cadmium and nickel for all three surveys conducted by AL/OEB. Samples that were conducted in the same manner or represent identical processes are statistically analyzed together. The only metals included in these tables are cadmium and nickel because these are considered the most important regarding waste issues. Attachment 1 gives a complete listing of analytical results for this effort.

TABLE 2. ANALYTICAL RESULTS FOR CADMIUM AND NICKEL (mg/L)

WASH WATER ONLY				
	CADMIUM TOTAL	CADMIUM DISSOLVED	NICKEL TOTAL	NICKEL DISSOLVED
High	37.9	32.8	14.9	14.2
Low	11	7.52	7.44	6.32
Average	16.77	14.87	10.49	9.58
Standard Deviation	15.09	12.87	3.66	3.60
Number of Samples	4	4	4	4
RINSE WATER ONLY				
	CADMIUM TOTAL	CADMIUM DISSOLVED	NICKEL TOTAL	NICKEL DISSOLVED
High	22.4	20.4	14.8	13.3
Low	6.76	6.99	2.25	2.18
Average	12.92	12.38	6.44	5.95
Standard Deviation	8.33	7.08	7.24	6.37
Number of Samples	3	3	3	3
COMBINED WASH AND RINSE				
	CADMIUM TOTAL	CADMIUM DISSOLVED	NICKEL TOTAL	NICKEL DISSOLVED
High	20.00	17.00	13.90	11.70
Low	0.09	0.15	0.06	0.07
Average	9.51	9.64	5.49	5.51
Standard Deviation	6.65	6.06	4.41	4.06
Number of Samples	9	7	9	7
FUSELAGE WASH				
	CADMIUM TOTAL	CADMIUM DISSOLVED	NICKEL TOTAL	NICKEL DISSOLVED
High	1.93	0.42	0.39	0.16
Low	0.07	0.05	<0.0005	<0.0005
Average	0.61	0.25	0.11	0.05
Standard Deviation	0.88	0.16	0.19	0.07
Number of Samples	4	4	4	4

The average cadmium and nickel concentrations for wash water samples for the three OEB efforts are 14.9 and 9.5 mg/L, respectively, for dissolved metals, and 16.8 and 10.5 mg/L, respectively, for total. For the rinse water the cadmium and nickel levels are 12.5 and 6.0 mg/L, respectively for dissolved, and 12.9 and 6.4 mg/L, respectively, for total. For composites of the wash

and rinse operations, the average levels for cadmium and nickel are 10.7 and 6.2 mg/L dissolved and 11.2 and 10.7 mg/L total, respectively. Levels of cadmium and nickel in the water from the fuselage wash are one to two orders of magnitude lower than those for the compressor washes. These values compare favorably with the total cadmium levels reported by OEMH (1994) from 22 wash and 23 rinse samples of 24.3 and 11.1 mg/L, respectively. QA/QC results indicated that sampling and analytical error were insignificant for both the 1995 OEBW and the 1994 OEMH studies.

Table 3, below, provides an estimate of cadmium contribution to total sanitary sewer flow for various daily flow rates. The calculations assume the compressor washing operation is conducted over a 30 minute period producing a maximum of 75 gallons of wastewater (50 gallons water plus 25 gallons soap), and that cadmium and nickel concentrations in the combining flow are negligible. Using the high and average concentrations of cadmium and nickel for combined wash and rinse water, we approximate the contribution of metals to the total flow. The amount of dissolved metals varies depending on other constituents in the sewage and the system, but will not be higher than total. This estimation also assumes that the flow from the wash operation is a "plug flow" through the system; no diffusion or spreading of the mass of water will occur as it travels through the sewer system. This is a highly conservative estimate which can provide useful information for bases which have concentration based effluent limitations. Actual concentrations are likely to be far below these values due to the diffusion of the wastewater in the sewer. These concentrations would occur as a 30 minute jump in the base effluent concentration, at some time after the washing operations. These values can be added to any existing concentrations at the base effluent to derive total concentrations.

TABLE 3. COMPRESSOR WASHING CONTRIBUTIONS TO SANITARY SEWER METALS CONCENTRATIONS

Base Flow (MGD)	**Total Cadmium (mg/L)** High	Average	**Total Nickel (mg/L)** High	Average
0.25	0.284	0.135	0.197	0.078
0.5	0.143	0.068	0.099	0.039
.075	0.096	0.045	0.066	0.026
1.0	0.072	0.034	0.050	0.020
1.5	0.048	0.023	0.033	0.013
2.0	0.036	0.017	0.025	0.010

For those bases which have total loading limitations, this data show a maximum and average cadmium loading of 5.7 grams and 2.7 grams, respectively, and a maximum and average nickel loading of 3.9 grams and 1.6 grams, respectively, per washing operation.

CONCLUSIONS

The compressor washing operations use approximately 75 gallons of water and soap per plane (4 engines). Table 2 of this report summarizes the analytical results for sampling conducted by OEBW at three Air Force Bases. Attachment 1 provides a detailed summary of analyses. These results should adequately characterize and represent the wastewater produced during C-130 compressor washing operations, and provide a basis for treatability studies and management decisions. The levels of cadmium and nickel generated by the compressor washing operations vary based on the washing operation, the elapsed time and hours of flying between washings, and the specific engines on the C-130, but should remain in the same order of magnitude indicated by the

OEMH and OEBW studies. Metals concentrations in the fuselage washes are one to two orders of magnitude less than the levels in the compressor wash wastewater. This result is expected because the cadmium and nickel components in the gas path are the source of the metals in the wash water. It also appears that the flying operations detach the metals from the engine components. The compressor washing process then carries these metals out of the engine. Based on the water-only compressor washes, and the fuselage washes, we do not believe that the metals are worn off by the washing operation. In addition, washes conducted with water alone do not have significantly different metals concentrations than those wash operations using soap.

RECOMMENDATIONS

OEBW recommends that compressor washing operations be conducted where the water can be collected or routed to the sanitary sewer, and that they be combined with fuselage washing in order to create a less concentrated wastewater. Private companies' treatability studies have provided evidence that the wastewater metals levels can be better reduced when starting with less concentrated samples. In-process dilution is a legally acceptable practice. This practice will also eliminate the extra man-power and scheduling required to move the plane to a washrack for fuselage rinses/washes, and then move it at another time to do the compressor washes. Whether the water is washed down the sanitary sewer or collected for recycling or other treatment, the less concentrated wastewater will be beneficial.

From both a management and a treatability standpoint, the levels of cadmium, nickel, and other contaminants, and amount of wastewater generated should be used to evaluate alternatives. These alternatives will likely be specific to individual bases and will depend on wastewater permits and state and local regulations. This study provides the data necessary for deciding how to treat, dispose of, or otherwise deal with the compressor wash wastewater.

REFERENCES

1. Weisman, Wade, 1995. Evaluation of C-130 Compressor Washing Operations Health Assessment. AL/OE-TR-95-0010.

APPENDIX A

Complete Analytical Results

APPENDIX A. COMPLETE ANALYTICAL RESULTS

BASE	TAIL #	#ENGINES	SAMPLE TYPE	SPECIAL CONDITION	CADMIUM TOTAL	CADMIUM DISSOLVED	NICKEL TOTAL	NICKEL DISSOLVED	TDS	TSS	SURFACTANTS
Little Rock AFB AK	793	1	wash	fh 249	11	9.95	14.9	14.2	850	1060	0.6
Little Rock AFB AK	793	1	wash		15.6	14.1	7.44	6.32	578	670	0.4
Little Rock AFB AK	793	1	wash		37.9	32.8	12.1	9.56	770	826	3.2
Little Rock AFB AK	793	1	comp	bb fs	11	10.7	6.47	6.52			
Little Rock AFB AK	793	1	rinse	early rinse	22.4	20.4	14.8	13.3	288	654	0.8
Little Rock AFB AK	793	1	rinse		6.76	6.99	2.27	2.37	360	384	0.35
Little Rock AFB AK	793	1	rinse		9.59	9.74	2.25	2.18	192	444	2
Little Rock AFB AK	793	1	comp	bb bs	13.5	15.2	11.7	10.2			
Little Rock AFB AK	793	4	comp	wr drain	0.092	0.152	0.074	0.059	440	454	12.6
Little Rock AFB AK		1	wash	H2O only	2.56	2.61	7.84	7.52			
Little Rock AFB AK	793	N/A	wash	ac fw	0.052	0.069	0.026	<0.031			
Little Rock AFB AK	793	N/A	wash	ac fw tp	0.423	1.93	0.39	1.163			
Patrick AFB FI	5833	4	comp	lcw 15days	3.8	3.6	2.9	2.6	4763	2910	0.6
Patrick AFB FI	5833	N/A	comp	saw	0.21	0.16	<0.0005	<0.0005	440	10	0.17
Patrick AFB FI	5833*	N/A	comp	saw	0.21	0.16	<0.0005	<0.0005	452	10	0.17
Patrick AFB FI	803	3	comp	lcw 6 mo	20	17	4.6	4.6	17,420	18	0.7
Patrick AFB FI	803	1	comp	efs	2.5		0.7				
Patrick AFB FI	803	1	comp	bb bs	8.5		6.3				
Patrick AFB FI	5830	N/A	comp	saw	0.33	0.3	0.023	0.015	7	484	0.41
Davis Monthan AFB AZ	1588*	4	comp	lcw unk	9.3	8.6	4.3	3.5	6820	7434	6800
Davis Monthan AFB AZ	1832	3	comp	H2O only	16.9	12.2	13.9	9.57	930	1700	70

Notes and Special Conditions:

* Duplicate Sample
comp - Composite of wash and rinse water
fh - Total flying hours since last compressor wash
bb fs - Baffle box engine front section (composite of wash and rinse water)
early rinse - Rinse water from the first 2 to 3 mininute of the first rinse cycle phase
bb bs - Baffle box engine back section (composite of wash and rinse water)
wr drain - Washrack drain Composite
ac fw - aircraft fuselage wash
ac fw tp - aircraft fuselage was collect from engine tail pipe
lcw - Last compressor wash
saw - Sea air fuselage wash
efs - Composite sample collected from engine front sectin without baffle box
H2O only - Compressor wash and rinse with water only

APPENDIX A. COMPLETE ANALYTICAL RESULTS

BASE	TAIL #	ALKALINITY	TKN	COD	AMMONIA	CHLORIDE	NITRATE/ NITRITE TOTAL	PHOSPHORUS	SULFATE	TOC	TPH	OIL & GREASE
Little Rock AFB AK	793	16		2070			0.5	0.68	89	430		102
Little Rock AFB AK	793	14		1130			0.68	0.61	71	132		288
Little Rock AFB AK	793	17		3040			4.6	0.93	96	29		336
Little Rock AFB AK	793											
Little Rock AFB AK	793	19		790			0.66	0.46	86	230		612
Little Rock AFB AK	793	15		200			0.6	0.23	34	25		59.2
Little Rock AFB AK	793	16					0.84	0.38	37			634
Little Rock AFB AK	793											
Little Rock AFB AK	793	99		750			<0.1	0.63	8	118		89.2
Little Rock AFB AK												
Little Rock AFB AK	793											
Little Rock AFB AK	793											
Patrick AFB Fl	5833	490		18,800	0.74	100	17.5	0.6	180		2900	8320
Patrick AFB Fl	5833	49		37	0.2	100	1.42	0.11	110		1.5	2.8
Patrick AFB Fl	5833*	50		31	0.2	100	1.42	0.34	114			
Patrick AFB Fl	803	1920	52	33,600	32	100	2.6	0.8	150		3096	14,600
Patrick AFB Fl	803											
Patrick AFB Fl	803											
Patrick AFB Fl	5830	50	1.1	82	0.2	87	4	0.35	114		20.6	29.5
Davis Monthan AFB AZ	1588*	662		25,200	1.6	25	2	1.6	120			312
Davis Monthan AFB AZ	1832	142		900	2	15	2.4	0.47	160			114.8